Solar Electric Future: Linking Science, Engineering, Invention and Manufacturing

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Outline

- **Status of Solar Electric in the U.S. and World**
- ***"Invented in the U.S. but commercialized overseas"***
- ***R*&D Program**
- **Future R&D and Equipment Needs**
- **Conclusions**

Mission

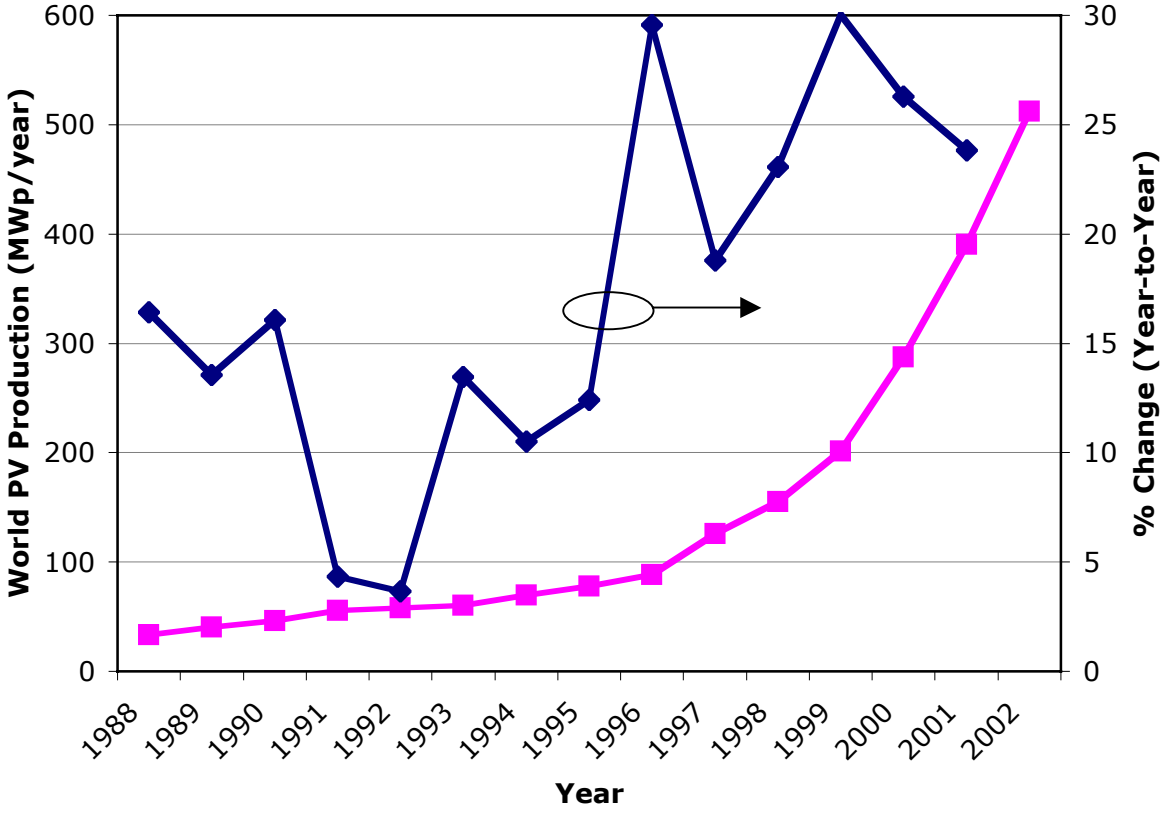
The Mission of the Office of Energy Efficiency and Renewable Energy (EERE) is to strengthen America's energy security, environmental quality, and economic vitality through public-private partnerships that:

- **promote energy efficiency and productivity;**
- **bring clean, reliable, and affordable energy technologies to the marketplace; and**
- **make a difference in the everyday lives of Americans by enhancing their energy choices and quality of life.**

The mission of the Solar Energy Program is to find ways to help meet America's energy needs through the development of solar energy devices and systems that are more efficient, reliable, and affordable.

Ref. FY 2004 Detailed Budget Justifications (EERE's portion of the President's Budget)

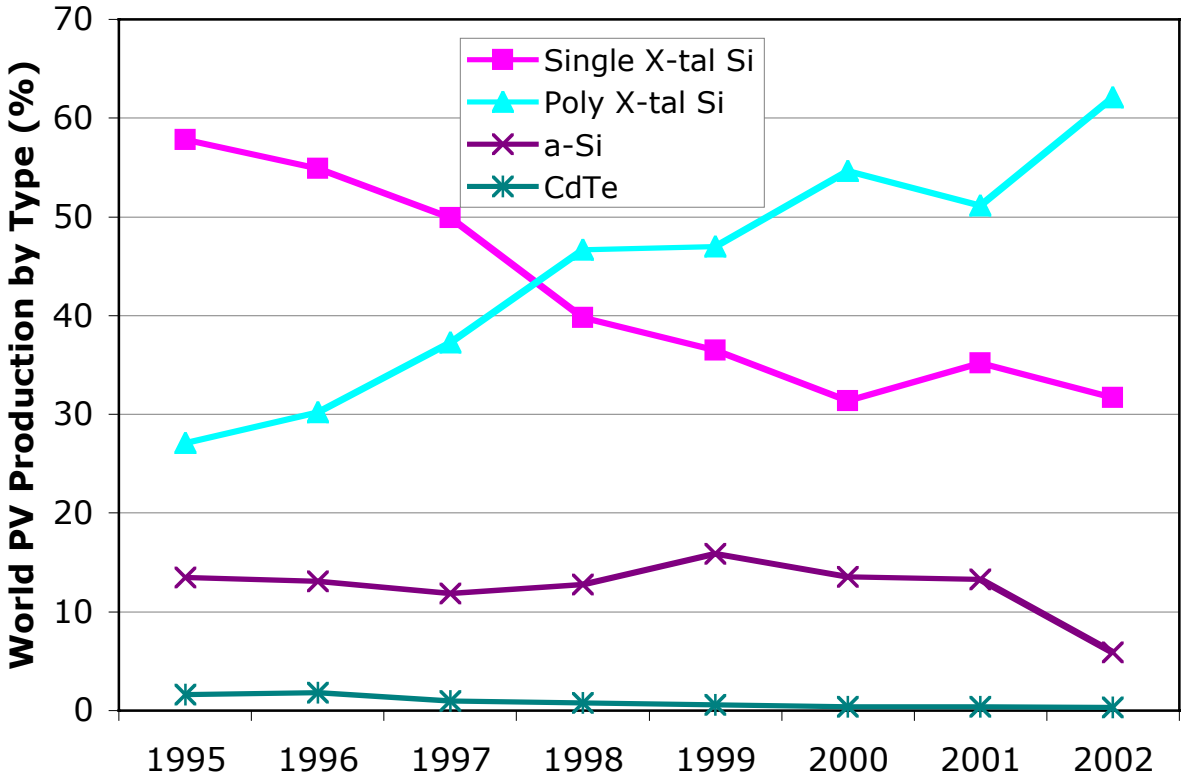
World Solar Electric Cell/Module Production



The world's PV production has been increasing at a rate of ~25% per annum since 1997 reaching ~ 512 MW/yr in 2003

From PV News, Vol. 22 No. 3, March 2003, Paul Maycock, Editor

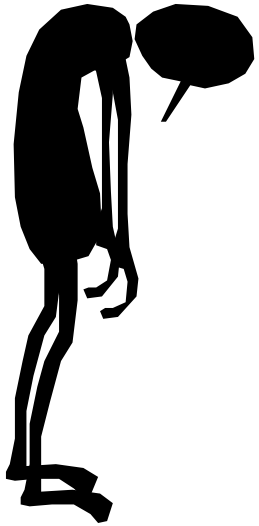
Production of Solar Electric Cell/Module by Type

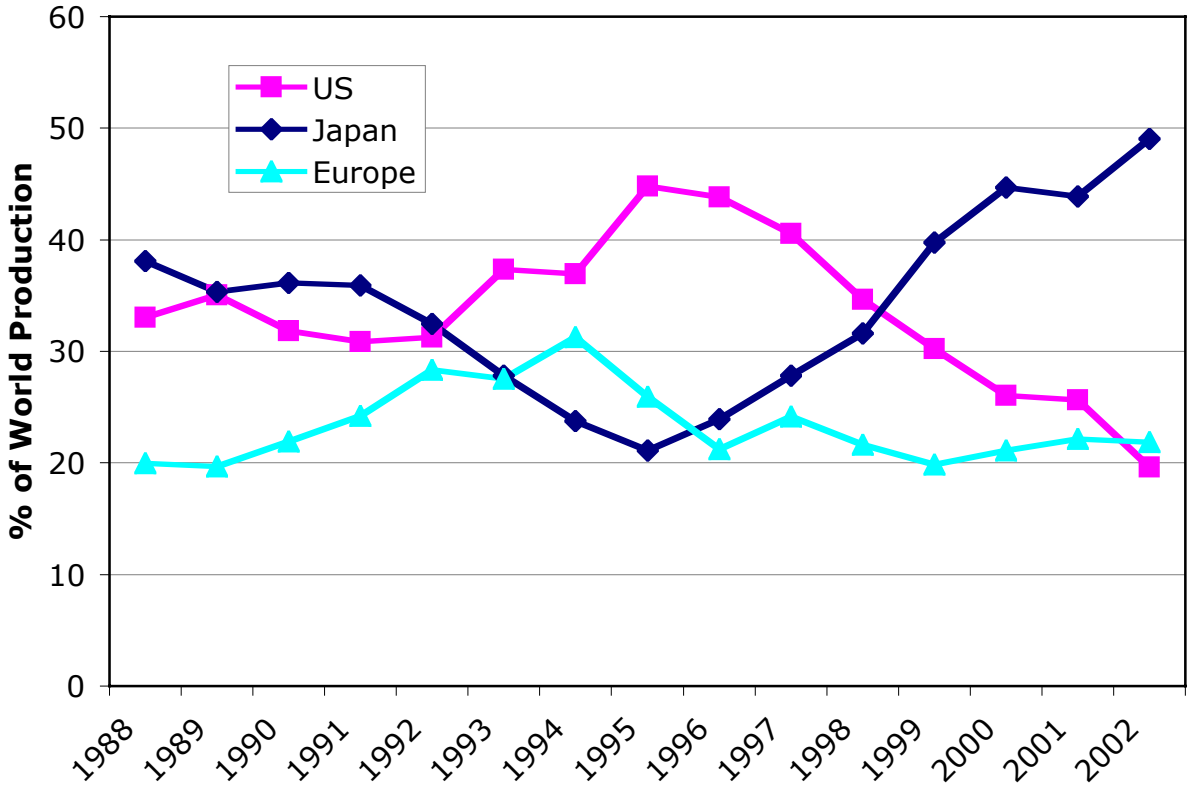


The fractional contribution of polycrystalline Si has increased steadily since 1995 and contributed over 60% of production in 2002⇒ ~280 MW

From PV News, Vol. 22 No. 3, March 2003, Paul Maycock, Editor

Production of Solar Electric Cell/Module by Region

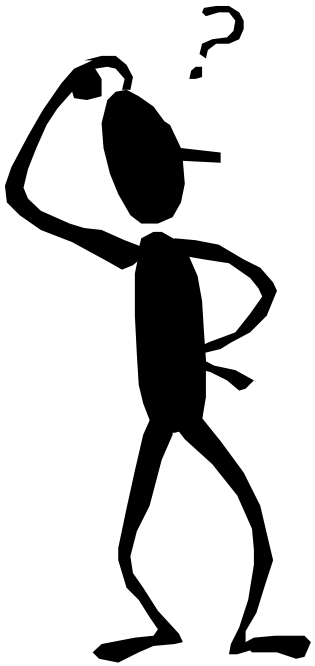


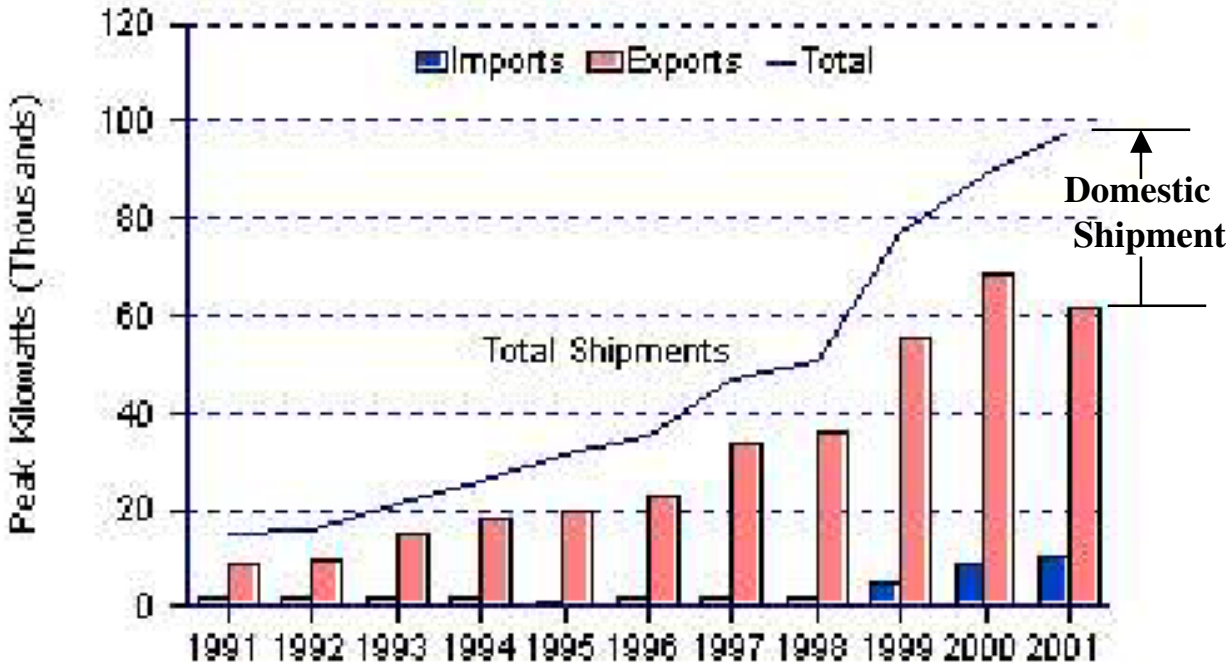


The U.S. contribution has steadily decreased since 1996 and in 2002 is less than Europe. Japan accounted for ~49% or ~ 251 MW

From PV News, Vol. 22 No. 3, March 2003, Paul Maycock, Editor

U.S. Import-Export Shipments of PV Cells &Modules

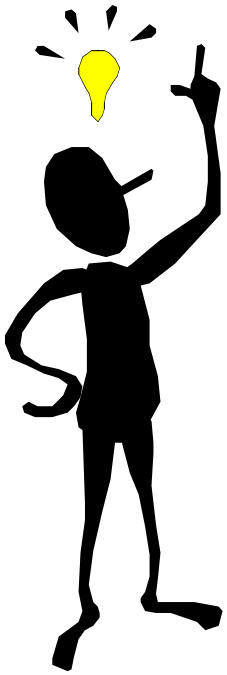


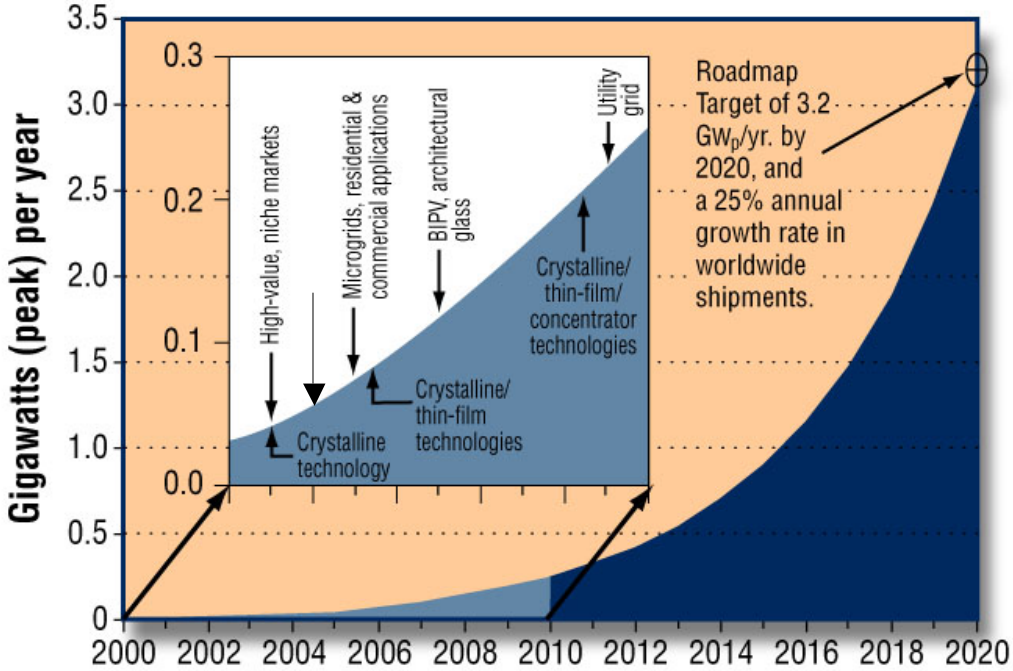


65-75% of U.S. shipments are exported. Domestic PV shipments between 2000 and 2001 increased from 19.8 MW to 36.3 MW

Source: Energy Information Administration, Form EIA-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Goal for U.S. Manufactured PV Modules





Goal for U.S. manufactured PV modules installed in U.S. domestic applications, for a U.S. market share that increases linearly from 30% to 50% from 2000 to 2020. Inset shows the evolution of the impact of various markets and technologies.

Source: Solar Electric Power, The U.S. Photovoltaics Industry Roadmap (April, 2001).

Future of U.S. Solar Electric

Is solar electric technology turning into another example of technology

"invented in the U.S. but commercialized overseas"?

Short answer: yes! (at least in the short term)

- **Loss of market share**
  - **Growth of PV in Japan due to government incentives and public education**
- **Slow growth of U.S. markets**
- **Proximity to world markets**

What can be done to change the trend?

PV Applications: Near Term Opportunities

Use high value applications as stepping stone to develop high-throughput, high-yield manufacturing technology which will reduce cost

- **Manufacturing cost, throughput and yield, not as critical**

High value performance driven applications: efficiency, portability, flexibility, power to weight

- **Energy security**
- **Distributed power generation**
- **'Clean power'**
- **Space and Military**

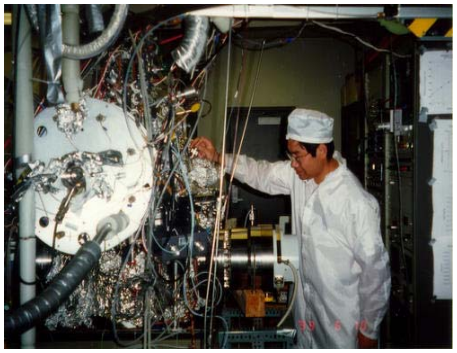
U.S. Position Going Forward

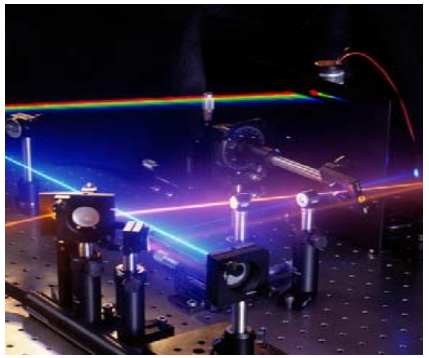
What can be done to improve the U.S. position in the future?

- **Robust R&D program to provide :**
  - **'next generation' technologies**
  - **science and engineering required to reduce the cost of PV modules**
- **Policy ⇔ Politics ⇔ Marketing**
  - **Need 'level playing field'**
  - **Incentive programs: Federal and State**
  - **Regulatory issues**
  - **Industry needs to develop stronger relationships with end-user e.g. utilities**

Solar Energy/Photovoltaic Energy Systems Program

The Solar Energy Program encompasses technology development from the seminal idea, through basic and applied research, to engineering development and technical readiness validation.





Ref. Detailed Budget Justifications (EERE's portion of the President's Budget)

Present R&D Programs

Fundamental Research

- **Measurements and Characterization**
  - **Advance fundamental understanding of efficiency-limiting defects in PV materials and devices using state-of-the-art characterization techniques**
- **PV Science Initiative**
  - **PV Technologies Beyond the Horizon**
    - **Non-conventional, breakthrough solar technologies**
  - **Future Generation PV Technologies**
    - **Basic research directed to thin films and new PV concepts**
- **High Performance Initiative**
  - **Increase efficiency**
    - **monolithically interconnected multi-junction thin films**
    - **super high efficiency multi-junction concentrator cells**

Present R&D Programs

Advanced Materials and Devices

- **Crystalline Silicon R&D**
  - **Improve throughput, conversion efficiency and lower energy and material costs**
- **Thin Film Partnership Program**
  - **Focus R&D on thin film technologies with the goal of transitioning at least two technologies from pilot plant status to multi-megawatt production**
- **Advanced Manufacturing R&D**
  - **In-situ process diagnostics and intelligent processing for integrated module manufacturing scale-up**

Present R&D Programs

Technology Development

- **System Engineering and Reliability**
  - **Critical needs to improve reliability and reduce life cycle cost of entire PV system**
- **Building Integrated PV R&D**
  - **Fully integrate PV into buildings and support Zero Energy Home activity**
- **Outreach and Analysis**
  - **Testing, verification, and deployment activities for grid connected applications and analyzing private sector commercialization options to better target R&D pathways**

Critical Issues: Fundamental Research

Need to develop the science and engineering base for thin film materials and devices required to effectively scale-up to large manufacturing facilities: *couple fundamentals with diagnostics & process control and equipment design & operation*

Over-selling new technology developments- 'next best thing to sliced bread'

- **Historically, *'new break-through will be in the market place next year'* results in disillusionment with PV and dilutes the importance of the technology**
- **The path from laboratory results to PV product takes time**

Critical Issues: Advanced Materials and Devices

Dissemination of critical results and know-how: 're-inventing the wheel'

Lack of relationship between processing parameters, material properties and device performance

- **Not able to predict cell/module performance until complete**
- **What do you use for process diagnostics and process control?**

Critical Issues: Equipment

Present state of equipment and facilities at national laboratories and universities is becoming antiquated

- **Down time for maintenance and repair increases dramatically with age reducing the time to address critical R&D needs**
- **State-of-the-art measurement and characterization facility is required to support all R&D efforts**
- **New equipment needed for advance process sensors and automated control and data logging**

New characterization tools need to be evaluated and used as product or process level sensors for process diagnostics and control

Future R&D Needs

Crystalline and Polycrystalline Si

- R&D can reduce cost, but world competition is major hurdle
- 'Policy ⇔ Politics ⇔ Marketing' required to regain the leadership position

Thin Film technology

- Presently in development or initial manufacturing stage:
  - Robust R&D programs needed to secure U.S. technological leadership

Next generation technologies

- Robust R&D programs are needed to keep the technology pipeline full

Approach

More integration between Fundamental Research, Advanced Materials and Devices, and Technology Development

- **Fundamental research on new technologies should be structured with an 'eye towards' manufacturing**
- **Increased focus by national labs and universities on engineering and scale-up issues associated with manufacturing**
- **Staff exchange programs between national labs, industry and universities**
- **Consortium funding to enhance collaborative research**

Coordinate federal R&D funding between agencies- DOE, DOD NASA etc.

- **DOE has the best technology know-how base: this needs to be exploited**

Conclusions

The present R&D PV programs provide a solid foundation for achieving more efficient, reliable, and affordable PV energy systems.

The trend of PV towards *"invented in the U.S. but commercialized overseas"* can be reversed

- **By robust R&D programs**
- **Through integrated Policy ⇔ Politics ⇔ Marketing effort**

Progress in the R&D programs could be accelerated by

- **Enhancing the focus of collaborative research efforts between national labs, industry and universities through staff exchange and consortium programs**
- **Inter-agency cooperation to develop high value applications**

Increase in R&D funding would accelerate progress!